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13. ABSTRACT *(Maximum 200 Words)*

ENERGEO, Inc. is engaged in a demonstration test program of its AGRIPOWER 200 unit fueled with biomass at Sutton Lumber Company in Tennga, Georgia. The objective of the program is to evaluate the operating and performance characteristics of the system using lumber wastes for fuel. The program is scheduled to accumulate 8000 hours of operation over a period of 1 to 2 years. The program became a reality due to initial funding from the U.S. Department of Defense's (DoD's) Strategic Environmental Research and Development Program (SERDP) and the U.S. Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (now referred to as National Risk Management Research Laboratory (NRMRL), Research Triangle Park).

The AGRIPOWER unit operates with an "open" Brayton cycle using a fluid bed combustor and several heat exchangers to heat compressed air which in turn drives a turbine/generator (T/G) set. The T/G set, which includes the compressor and a recuperator, is a Solar "Spartan" unit packaged for this application by Alturdyne, Inc. The combustor utilizes both in-bed and freeboard combustion zones, and the above-bed zone is well mixed to provide uniform temperatures.

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Design specifications call for consumption of 829 lb/hr (376 kg/hr) of fuel with a lower heating value of 4,270 Btu/lb (9.92 MJ/kg). The net electrical power output will be approximately 200 kW-hr/hr. This corresponds to a heat rate of 17,700 Btu/kW-hr (41.3 MJ/kW-hr). The capital cost of an AGRIPOWER 200 unit will be approximately $2,250/kW of capacity.

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INTRODUCTION

Around the world, both in developing and developed nations, there exist areas in which there is little or no electrification. Often, because of population sparsity or geographical obstacles, there is little anticipation that these areas will ever have electric power as part of a distribution system connected to central power plants. Currently, where electricity is to be provided, it is, and will be, provided by small diesel generator sets which are the predominant small units. Unfortunately, diesel generators consume 0.07 to 0.10 gallon (0.27 to 0.38 liter) of oil per kilowatt-hour generated. Even at subsidized prices of $1.00/gal ($0.26/liter), the fuel cost alone for generating electricity amounts to $0.07 to $0.10/kW-hr generated. In many locations where diesel oil prices are $2.00 to $4.00/gal ($0.53 to $1.06/liter) the fuel costs alone amount to $0.14 to $0.40/kW-hr generated. With many of the developing areas experiencing an imbalance of trade, there is a clear incentive to develop alternative sources of energy.

Of the choices of renewable energy sources, biomass is one alternative which offers the possibility of delivering 24 hr/day electrical service in capacities needed to provide small communities with the power for domestic, agricultural, and industrial applications. Power generators which produce 100 to 200 kW-hr/hr of electricity can provide electrification for communities of 100 to 300 people. Throughout the world there exists tremendous quantities of biomass waste, such as wood waste, rice husks, sugar bagasse, and coconut shells, which is available as fuel. Using biomass fuel to generate electricity is environmentally favorable, economically viable, and feasible within the resources of developing areas.

In response to the need for biomass-fueled electrical generators, ENERGEO, Inc., of San Mateo, California, has designed a 200 kW electrical generating system combining two existing and well founded technologies: gas turbine technology and fluid bed combustion technology. The system is modular, prefabricated for shipment to the site of application, and installed and put in operation on site in several weeks. The capital cost of the AGRIPOWER 200 unit is currently $2,250/kW of delivered electrical power f.o.b. manufacturing facilities in California. This cost may be reduced through manufacturing efficiencies and/or partial fabrication of the unit in the country of end use.

ENERGEO has received extensive worldwide interest in the AGRIPOWER 200 unit, including letters of intent to purchase significant quantities when the operation of the commercial version has been demonstrated. In support of the development and application of small biomass-fueled technologies, and to foster U.S. exports, a commercial demonstration of ENERGEO's AGRIPOWER 200 unit was undertaken with funding and participation from the EPA's NRMRL, DoD's SERDP, the U.S. Department of Energy's (DOE's) Office of Solar Energy Conversion/Solar Thermal

and Biomass Power, the Tennessee Valley Authority (TVA), and Sandia National Laboratories.

The demonstration of the AGRIPOWER 200 unit is scheduled to accumulate 8000 hours of operation over a period of 1 to 2 years at Sutton Lumber Company in Tennga, Georgia. The objective of the demonstration project is to evaluate the operating and performance characteristics of the system using lumber wastes as fuel. It is hoped that the project will establish the technical and economic feasibility of the technology and document the environmental impact. Efficiency and emissions testing will be performed by independent experts. Additional fuels may be included in the program at a later date. The supporting agencies have the option of extending the program for an additional year and another 7000 hours on line.

AGRIPOWER TECHNOLOGY

The AGRIPOWER 200 unit is an energy conversion technology fueled with biomass to produce electricity and heat energy. The system operates with an "open" Brayton cycle using a fluid bed combustor and several heat exchangers to heat compressed air which in turn drives a T/G set. The Solar "Spartan" T/G set, including a compressor and a recuperator, is being packaged for this application by Alturdyne of San Diego, California. The balance of the system was designed by ENERGEO and fabricated by PMC Production in Sacramento, California. A turbine combustor included in the system is used for start-up and may be used to supplement the biomass fuel for maximum output and/or trim control of the turbine speed. The electricity generated will be utilized by the lumber mill with additional electricity supplied to the grid and sold to the TVA. The system also discharges clean hot air which can be used for cogeneration.

The process is shown schematically in Figure 1. There are two primary flow circuits in the process: a compressed air turbine circuit and a combustion circuit. The compressed air turbine circuit begins with the intake of ambient air by the compressor which is powered by direct connection to the turbine. The air is compressed to several atmospheres and exits through a recuperator which transfers heat from the turbine exhaust to the compressed air and improves the efficiency of the system. From the recuperator, the compressed air passes through a convective heat exchanger, recovering energy from the furnace flue gases. Then the compressed air goes to the furnace and receives additional energy via a radiant heat exchanger in the upper part of the furnace above the fluid bed. From the radiant exchanger the compressed air returns to the turbine and expands through the turbine blades to power the compressor and the electrical generator. The turbine exhaust then passes through the recuperator and is either discharged to the atmosphere or utilized for cogeneration. Included as an integral part of the turbine is a fuel oil combustor which is used for "black" starts of the system.

The combustion circuit uses two fans to supply air to the fluid bed and the freeboard above the bed. Both air supplies are preheated by recovering energy from the flue gases. Biomass fuel is supplied to the furnace by a feed hopper and screw conveyors. Two screws located in the bottom of the hopper regulate the flow of fuel to a third screw which injects the fuel above the fluid bed. The furnace employs both in-bed and freeboard combustion zones. The freeboard zone is well-mixed to provide uniform temperatures. The temperatures both in and above the bed are regulated to limit potential problems associated with the ash. After giving up energy to the compressed air through the radiant and convective heat exchangers, the combustion gases pass through a cyclone for removal of the fly ash. From the cyclone, the flue gases are used to preheat the combustion air streams via the air preheaters. An induced draft fan exhausts the flue gases to the atmosphere and is controlled to maintain a slight negative pressure in the furnace above the bed.

The motors for the fuel feed screw conveyors and for all fans are variable speed as part of the system control. Feedback from the power output by the electrical generator and the inlet temperature to the turbine are used to regulate the amount of fuel supplied to the furnace. Key furnace temperatures are used to control the combustion air supply. Individual controllers are utilized for each principal control loop. The individual controllers are supervised by a digital computer providing overall control of the system. If a computer fails, the individual controllers can operate independently. Under certain circumstances the computer can override the individual controllers and control the components directly. While the control system may appear complex, the interfaces with the AGRIPOWER unit operators are very simple. Start-up and shutdown procedures are programmed into the system computer. One of the issues to be resolved during operation of the AGRIPOWER unit at Sutton Lumber is the best method for control of the turbine speed. Several possibilities exist to be evaluated.

DEMONSTRATION PROGRAM

The AGRIPOWER 200 unit to be installed and tested at Sutton Lumber Company is the basic design intended for distribution to the market place. Prior to shipment to Sutton Lumber Company, the unit will be assembled and operated by ENERGEO for "shake down" in Sacramento, California. At the lumber mill, the unit will be operated by Sutton personnel as part of their ongoing power generation from wood wastes. The unit is expected to operate 24 hr/day in a base-loaded mode. The test will continue for 8000 operating hours or for 2 years, whichever comes first. The supporting agencies have the option of extending the test for another year and an additional 7000 operating hours. Performance and environmental testing will be conducted by independent experts. The AGRIPOWER unit is equipped with a number of pressure and temperature instruments for recording operating data on a continuous basis. For assistance in evaluation and

diagnosis, Sandia National Laboratories will provide additional instrumentation and data gathering facilities. Through the continuous data gathering, operating and maintenance logs, and scheduled tests by the independent experts, the test program will document the operating and maintenance characteristics, determine the process performance, and define the potential environmental effects of the operating unit.

Operating and Maintenance Characteristics

ENERGEO's AGRIPOWER unit is designed for simple operation and maintenance with a minimum of labor required; an important part of the program is to verify and improve upon these design objectives. The operating experiences will be logged throughout the demonstration program. The condition of equipment, both internally and externally, will be evaluated by inspection at the end of the program. Factors of consideration to be determined include:

- Operation
  - manpower hours
  - expenses
  - unexpected events
  - start-ups and shutdowns
- Maintenance
  - manpower hours
  - expenses
- Reliability
  - scheduled downtime
  - unscheduled downtime
- Equipment durability
  - wear/failure
  - corrosion
  - slagging/fouling
- Instruments and controls
  - equipment/operator interfaces
  - start-up procedures
  - shutdown procedures
  - emergency procedures
  - load following

Process Performance

Design specifications for the Sutton installation call for consumption of 829 lb/hr (376 kg/hr) of fuel with a lower heating value of 4,270 Btu/lb (9.92 MJ/kg). The net electrical output will be approximately 200 kW-hr/hr at the specified maximum capacity. This corresponds to a heat rate of 17,700 Btu/kW-hr (41.3 MJ/kW-hr). The performance goals call for a capacity factor of 95% which would yield a total cost (capital and

operating expense) of $0.06/kW-hr of electricity generated. The initial capital cost of an AGRIPOWER system for general distribution would approximate $2250/kW of installed electrical capacity. For cogeneration applications, the 18,000 lb/hr (8163 kg/hr) of turbine exhaust leaving the recuperator still retains a temperature in excess of 500 °F (260 °C). When this energy is used to displace fuel oil for drying, generating steam, or for other processes, significant savings can be obtained to the extent that the cost of generating electricity may be totally offset.

Important temperatures and pressures will be logged automatically as part of the AGRIPOWER control system. In addition, Sandia National Laboratories will provide instrumentation and data recording capabilities to supplement the AGRIPOWER equipment. Data capabilities will provide for the performance evaluation of the system as well as individual components. Performance parameters of interest include:

- Energy generated
  - electrical power produced
  - thermal energy discharged

- Fuel consumption
  - quantity
  - quality

- System performance
  - efficiency and heat rate
  - availability and capacity factors

Environmental Aspects

Atmospheric emissions will be determined by periodic sampling according to standard EPA test procedures. Emissions of interest are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and particulates. Biomass fuels sometimes contain small amounts of sulfur and nitrogen. The wood waste at Sutton Lumber has been reported to contain 0.04 wt% sulfur and 0.11 wt% nitrogen, both on a dry basis. The sulfur content yields SO_2 emissions of 0.36 lb/hr (0.16 kg/hr) or 0.10 lb/10^6 Btu (0.046 kg/10^6 kJ). The combustion temperatures within the AGRIPOWER combustor are low enough to avoid any significant fixation of atmospheric nitrogen to produce thermal NO_x, and essentially all of the NO_x emitted by the unit is anticipated from partial conversion of the fuel nitrogen. NO_x emissions are estimated to be 0.40 lb/hr (0.18 kg/hr) or 0.124 lb/10^6 Btu (0.053 kg/10^6 kJ). The combustion in the furnace is well mixed with sufficient residence time to minimize CO emissions which have been estimated to be 0.71 lb/hr (0.32 kg/hr) or 0.220 lb/10^6 Btu (0.094 kg/10^6 kJ). The ash content of the fuel is 1.0% on a dry basis, and most of the ash is collected in the cyclone. Particulate emissions in the flue gas exhausted from the cyclone are estimated to be 0.46 lb/hr (0.21 kg/hr) or 0.13 lb/10^6 Btu (0.059

$kg/10^6$ kJ). The fuel is apparently free of any chloride content, so hydrogen chloride emissions will be nil.

Ash is discharged from the unit at several points in the process. A small amount of ash is removed from the bottom of the furnace as part of the process of purging the fluid bed of tramp materials. The major portion of ash is collected as fly ash in the cyclone and discharged from the bottom of the cyclone. The remaining ash is discharged as particulates in the flue gas. For each discharge point there is interest in determining the quantity and composition of ash.

Schedule

The original project plan scheduled the AGRIPOWER unit shipment in July 1994 to Sutton Lumber Company for start-up in August. That schedule has been affected by some contractual and material supply problems. Currently, the plan calls for preshipment testing and shipment in August 1995. Start-up is scheduled for September 1995 with viable operation accomplished during 1995.

CONCLUSIONS

Direct combustion of biomass currently offers the simplest and most economical process for recovering energy from biomass wastes. Throughout the developing areas of the world there exists a huge potential demand for AGRIPOWER 200 units. ENERGEO has received letters of intent to purchase significant quantities of the AGRIPOWER 200 units contingent on successful operation of the demonstration unit. The waste heat from the system can be used to produce potable water and ice as well as for drying food and industrial products. Much of the worldwide demand for AGRIPOWER includes interest in cogeneration for water and ice. Future plans include design and fabrication of larger units which will meet some of the greater demands of industrialized applications. As a proven system, the AGRIPOWER units will fill a significant worldwide need and contribute to U.S. exports and trade.

ACKNOWLEDGMENTS

This project became a reality due to initial funding from the DoD's SERDP, and funding and participation from the U.S. DOE's Office of Solar Energy Conversion/Solar Thermal and Biomass Power, the EPA's NRMRL, the TVA, Sandia National Laboratories, ENERGEO, Inc. of San Francisco, California, PMC Production, Inc. of Sacramento, California, Sutton Lumber Company of Tennga, Georgia, and International Applied Engineering, Inc. of Atlanta, Georgia. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FIGURE 1: AGRIPOWER PROCESS -- SCHEMATIC